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IN AIRCRAFT REENTRY MEASUREMENTS

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Design Principle of Memory Retransmission in Aircraft Reentry Measurements

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Abstract: This paper presents an analysis of some key problems in designing a radio telemetry memory retransmission system applied to aircraft reentry measurement, including the relationship between memory time and blackout time, the relationship between retransmission period and recovery time, determination of memory retransmission ratio and memory retransmission modes. It also touches upon the design principle, experience, computation method and test results of these technical problems.

Key words: reentry measurement, memory retransmission

1. Relationship Between Memory Time and Blackout Time

Memory time refers to the period of time from data being written in storage until the data is replaced by new data when the storage is full, which is shown with t_1. When an aircraft reenters the atmosphere, radio communications are blacked out due to a plasma sheath around the aircraft. The time from the start of the black out to the recovery of communications is the blackout time t_2. Only with appropriate coordination between the memory time and retransmission time, can the memory retransmission system acquire the entire data of the blackout zone.

The purpose of memory is to store the information from the blackout zone so as to retransmit it when blackout is over. If the memory time is shorter than the blackout time, then the data

which first enter storage in the blackout zone will be replaced by new data after memory time t_1 and can by no means be transmitted to ground because the blackout is not yet over. Only those data which enter storage later than blackout can be transmitted to ground when the blackout disappears, while the data which are replaced when blackout is still on will be totally missing. The aim of designing the system is to acquire all the data in the blackout zone and the aim can hardly be realized if the memory time is shorter than the blackout time.

What will happen if the memory time is equal to the blackout time?

The time needed for an actual communications system to retransmit large amounts of data under memory is called the retransmission period, which can be expressed in the following equation:

$$t_3=c/v \tag{1}$$

where t_3 is retransmission period;
c is storage capacity (bytes);
v is retransmission rate (byte/s).

If the memory time is equal to the blackout time, the aircraft will be located in the blackout zone all the time while the data that are stored in the instant of blackout start stay in the storage. These data, being replaced when blackout is just ended, cannot be transmitted to ground, either. Under the condition of $t_1=t_2$, not only the above-mentioned data cannot be transmitted to ground, but also those which enter the storage in a period of time from blackout start to less than a retransmission period after the blackout cannot always be transmitted to ground. This is because the order of reading and data replacement is random, i.e. not every reading is before

replacement and therefore, whether or not these data can be transmitted to ground is also random. Under the condition of $t_1=t_2$, the maximum time length, during which data could be missing is just a retransmission period t_3.

If the memory time is prolonged to meet the condition of Eq. (2), i.e.

$$t_1=t_2+t_3 \tag{2}$$

then the data that enter storage at the start of blackout will continue staying there for a t_3 time before being replaced by new data. In other words, the data will wait for a retransmission period t_3 after blackout is over and thereby can surely be transmitted to ground after blackout is ended. However, they are retransmitted only once after the blackout and can reach the ground, while several retransmissions done before the blackout are conducted in the blackout zone and thereby cannot be received by ground. Thus, $t_1=t_2+t_3$ is a critical condition, under which the entire data in the blackout zone can be transmitted to ground.

A ground simulation test confirmed the correctness of this analysis. The conditions and method of the simulation test were as follows: the memory time t_1 of the memory retransmission system was fixed at 32s, the retransmission period t_3 was fixed at 2.6s, while different blackout times t_2 were designed to meet the following three conditions:

$$t_1<t_2+t_3$$
$$t_1=t_2+t_3$$
$$t_1>t_2+t_3$$

to examine the three data transmission forms of the memory retransmission system. First, let the memory retransmission system and ground receiving system operate with electricity; a special waveform was used to represent the retransmitted data

from the transmission system as shown in Fig. 1.

Fig. 1. Waveform of Transmitted Raw Data

In Fig. 1, the abrupt decrease of 5V to the trailing-edge of 0V is regarded as time zero point of the "blackout" start. When the zero second signal is transmitted, the ground does not receive the transmitted signal to indicate a signal interruption. Following a delay time t_2, the ground begins receiving the transmitted signal and recovering the waveform. The test results are displayed in Figs. 2, 3 and 4.

Fig. 2. Memory time: t_1=32s
Blackout time: t_2=28s
Retransmission time: t_3=2.6s

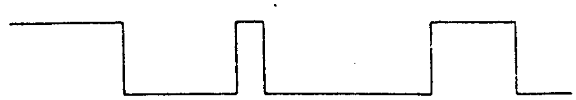

Fig. 3. Memory time: t_1=32s
Blackout time: t_2=29.4s
Retransmission time: t_3=2.6s

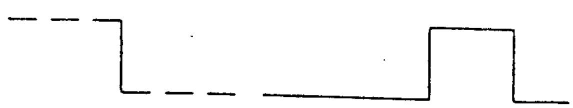

Fig. 4. Memory time: t_1=32s
Blackout time: t_2=30s
Retransmission time: t_3=2.6s

Figures 2 and 3 indicate that since the system can meet the condition $t_1 \geq t_2 + t_3$ and therefore, all the memory data in the zones can be completely retransmitted to ground when the blackout is over and the waveforms of the raw data can be recovered although the aircraft has overflown the "blackout zones" 28s and 29.4s. It can be seen in Fig. 2 and 3 that the waveforms are complete without missing points. While the picture in Fig. 4 is different. Although the memory time (t_1=32s) is longer than the blackout time (t_2=30s), still part of the information stored at the beginning of the blackout is missing (see the imaginary line of the waveform) just because $t_1 < t_2 + t_3$ and moveover, the missing part is increasing with the increasing difference between t_1 and $t_2 + t_3$. It can be concluded from here that in order not to miss the data memorized in the blackout zone, the memory retransmission system should be designed so that it could meet the following condition:

$$t_1 \geqslant t_2 + t_3 \tag{3}$$

The time length of the blackout zone, affected by factors like aircraft properties, performance of the measurement system and so on, is a quantity difficult to control and accurately compute. While the memory time and retransmission period are quantities which can be adjusted through telemetry equipment and telemetry system design. Therefore, it is necessary to adjust and control t_2 and t_3 so as to meet this condition.

The memory time relies on the capacity of the memory storage and the write-in rate of information. Obviously, excessively

prolonging the memory time t_1 may not only unnecessarily increase the storage capacity, but also require a higher retransmission rate; if not, a longer retransmission time will be necessary. Nonetheless, since the blackout time is difficult to compute accurately, the actual interruption time may be greatly different from the estimated value. Thus, to meet the foregoing condition, a sufficient margin should be left in designing the memory time and retransmission period.

2. Relationship between Retransmission Period and Communications Recovery Time

Communications recovery time t_4 refers to the time from blackout disappearance and communications recovery to the aircraft touching the ground (water). All the data stored in the blackout zone should be quickly retransmitted to ground during the communications recovery time. Obviously, the retransmission period must be designed shorter than the communications recovery time. Considering some factors--such as the communications recovery time is as difficult to accurately compute as the blackout time, the telemetry receiving antenna has an extremely low elevation and its reception performance gets worse when the aircraft is flying at a low altitude, and retransmission has to repeat 2-3 times so as to raise the quality and reliability of the retransmitted data that the telemetry station acquires, etc.,-- the theoretically estimated recovery time should not be fully utilized. It is appropriate to select a retransmission period t_3 based on Eq. (4)

$$t_3=(1/4-1/6)t_4 \tag{4}$$

The design parameters of the measurement system should be adjusted in accordance with the constraints of Eq. (4) so that the retransmission period t_3 can not only satisfy the requirements of Eqs. (3) and (4), but also maintain more rational

overall indexes of the measurement system so as to eventually meet the overall measurement requirements.

Take a certain model as example. Its recovery time was estimated to be 10-12s and accordingly, the retransmission period was designed as 2.6s. As a result, all the data in the blackout zone were acquired during the test flight, and the memorized data were received 2-3 times.

3. Memory Retransmission Ratio

The ratio between the memory time and retransmission period is referred to as memory retransmission ratio:

$$n=t_1/t_3 \tag{5}$$

When the aircraft is in the reentry period, the blackout time is extremely long (usually ranging from several to dozens of seconds), while the recovery time is very short (generally between fractions of a second and 10-20 seconds). To avoid missing the blackout zone data, a longer memory time and a shorter retransmission period should be taken, which form a slow memory--quick retransmission mode. In a missile seeker reentry measurement system, the memory retransmission ratio is designed as high as 8:1, 12:1 or even 16:1.

A large memory retransmission ratio can help measure more data in the blackout zone and retransmit large amounts of information to the ground during the shorter recovery time. But on the other hand, it will take a large part of the transmission code rate of the measurement and communications system, and the data retransmitted with this part of code rate are meaningless in the rest of the flying period. Therefore, it will be unwise to design a large memory-retransmission ratio at the expense of

other performance of the measurement system (such as the information volume retransmitted in real time). It is necessary to select an appropriate memory retransmission ration in designing the system based on various factors.

Should memory retransmission ratio n be an integer? When the memory retransmission ratio is an integer, the data volume read out each time (each signal frame) from the storage is just the integer multiplication of the data volume written in the storage in the same instant. If the data words written in the storage at the same time, together with the service signal words, are edited as a complete frame structure (hereinafter referred to as a memory frame), then with such a scenario, each frame of retransmitted signals (hereinafter referred to as a signal frame) that the telemetry station receives contains complete memory frames, and the number of memory frames contained in one signal frame is equal to the memory retransmission ratio n.

If the memory retransmission ratio is a fraction, not all the memory frames in each signal frame are complete, and the incomplete memory frames can possibly happen at the beginning or end of a reading, or both.

Such incompleteness of memory frames in a signal frame does not affect the after data processing because the retransmission law of the storage readings remains unchanged in the same data collection program, i.e. one time a part of the memory frame is read off, and the immediate next time another part is read out first, which is actually the leftover of the last reading. If the received memory frames are put together one by one in the order of time, these retransmitted decollated memory frames can be restored to the original complete form. The structural relationship between the memory frames can easily be re-recovered if the data processing program is carefully edited. The above-mentioned model adopted a fractional memory-retransmission ratio

12.23:1 and successfully realized the patching of the decollated memory frames in data processing process. Therefore, in designing a telemetry system, the memory retransmission ratio can be determined in accordance with the overall requirement of the system without needing to worry about whether or not the ratio should be an integer or fraction, and it is even more unnecessary to fill measurement-unrelated filler characters in the memory retransmission data flow, and waste precious information volume just to acquire an integer memory retransmission ratio.

Here, we highlight maintaining or recovering the structural completeness of memory frames only because the sequence of data words in the memory frame structure contains the code name, quantity value, time and synchronization, etc. Thus, if the structural relationship between memory frames cannot be recovered, all the data in the frames will be useless.

4. Memory Retransmission Modes

The memory retransmission modes can be divided into a slow memory and quick retransmission mode (n>1) and parallel delay retransmission mode (n=1) in terms of the size of memory retransmission ratio. Also it can be divided into a time sequence memory retransmission mode, i. e. the data memorized first are retransmitted first and the data memorized later are retransmitted later, and a non-sequence selected point retransmission mode. The parallel delay mode is basically used for measuring data acquired during the carrier rocket interstage separation period, head and body separation period or satellite-rocket separation period, while the slow memory and quick retransmission mode--for measuring data during aircraft reentry period. The time sequence mode is usually used in combination with the parallel delay mode, while the selected point mode is generally utilized in the slow memory and quick retransmission mode. The following discussion is devoted to the principle,

advantages and disadvantages of the sequence mode and selected point mode.

If the ground receives signals from a segment of the retransmission period due to some reason, signals from this segment contain only those data collected in a corresponding period of time in the blackout zone. Despite the extremely high parameter sampling frequency (generally 40-50 Hz) and its large or even excessively large number of sampling sites, there is no single data site in the missing period of blackout. In this case, the sequence memory retransmission mode, though retransmitting sufficient data to the ground, can hardly reflect the modification of parameters in the entire blackout zone and even miss the parameter polarization points or characteristic points. Obviously, the sequence mode is not suitable for reentry measurement.

If the order of data retransmission (i. e. the order of reading in the storage) is changed so that the memory frames in each signal frame that the telemetry station receives are selected from all those in the entire blackout zone evenly and in the order of time, then such selection will increase the time interval between sampling sites, although there are only a small number of memory frames retransmitted in a signal frame. And since each received frame of memory data obeys this kind of law and there is no repetition of frames in time, with the increasing number of received signal frames, the accumulating number of received memory frames will accordingly increase, the interval of data sampling sites will gradually decrease and the frequency of data appearance will gradually approach the original sampling frequency. If telemetry signals of one retransmission period can continuously be received, all the sampling site data collected by memory parameters in the blackout zone can be received, and the density of data sampling sites can restore to the collection density. This is the selected point memory retransmission mode.

It can be seen that this retransmission mode is superior in that once a frame of telemetry signals (generally from only 0.02 to 0.025s) are received during the recovery period, n (memory retransmission ratio) data sampling sites of all memory parameters in the blackout zone can be acquired. The n data are no longer collected in a certain instant from the blackout zone, but evenly selected from throughout the blackout zone. Therefore, they are more typical. For instance, if the blackout time is 29s and the memory retransmission ratio is 12, then when one frame of signals are received, each memory parameter can obtain 12 data sampling sites in the blackout zone, which are evenly selected from the zone. With this small number of data, a general picture of the parameter modification in the entire blackout zone can be derived. The more signal frames are received, the larger the density of data sampling sites can be and the clearer the parameter variation details. Therefore, this type of memory retransmission mode is not only rational, but also highly reliable in data acquisition.

To realize the selected point memory retransmission, the read-out data can be evenly selected from those stored in the order of time as described above and also, the write-in data can be stored in accordance with a certain law instead of in the order of time and address so that during reading in the order of storage location, the memory data in each signal frame can meet the selected point retransmission law.

5. Dynamic Process of Memory Retransmission

There is a misunderstanding that the memory retransmission system for use in blackout zone reentry measurement is to store the memory data to be measured at the start of blackout and quickly retransmit them as soon as blackout disappears. If so, a

technical problem is difficult to solve, that is: When does blackout start? When does it end? How can we distinguish various kinds of blackout information and turn it into control instructions for memory and retransmission? At present, it is impossible to preset program instructions based on the computation of the starting and ending time of the blackout in engineering.

While the memory retransmission system is applied to an actual reentry measurement, it can avoid the foregoing technical difficulty.

Starting from the electricity operation of the system, the data to be memorized are written in storage in order again and again until the storage is full, when newly collected data will replace the old data. The order of data replacement is the same as that of data write-in, i.e. data written first are replaced first and accordingly, data written later are replaced later. In the time sequence memory retransmission system, the order of storage location reading is in complete agreement with the order of writing. But in the selected point memory retransmission system, the reading law does not conform to the writing law. In this case, it is possible to write in based on the storage location order and read out in accordance with the even point selection law, or vice versa. In the meantime, reading out, editing signal frames and transmitting can be conducted at a rate, n times faster than the write rate. Let us look into the dynamic process of one of the hypothetical parameters. During memory time t_1, it can automatically write to storage and may be read out first. Since write and read are at different rates, its first read-out time is random but will not surpass the retransmission period t_3. After another t_3, it is read out again (it will not disappear when data are being read out, and will be

replaced by a new measured value of that parameter only after t_1). During the entire memory time t_1, the read out times k is:

$$k=t_1/t_3=n \qquad (6)$$

In other words, during one memory time, the times of read-out of each measured value of each memory parameter is equal to the memory retransmission ratio n. This data can be received n times, and when the process is interrupted due to blackout, the read out and retransmission will still be continuing but the ground cannot receive any. If $t_1=t_2+t_3$, the first write-in data frame after blackout appearance will surely be received by the ground once, which is also the last time before the data are replaced by new data, while the later write-in data will be received 2 times, three time... until n times.

With such an operation mode, the memory retransmission system can cleverly dodge the above-mentioned control instruction problem at the expense of a part of transmission code rate. This was successfully accomplished in a test flight of a certain model.

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